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Economic Implications of Regulating Nonaerosol Chlorofluorocarbon Emissions An Executive Briefing

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This report documents a briefing presented to the Environmental Protection Agency on November 29-30, 1970. It summarizes the results of a three year Rand study of the economic implications of alternative policy approaches for controlling emissions of chlorofluorocarbons (CFCs) in the United States.

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ECONOMIC IMPLICATIONS OF REGULATING CHLOROFLUOROCARBON EMISSIONS FROM NONAEROSOL APPLICATIONS: AN EXECUTIVE BRIEFING

Contract No. 68-01-3882
& 68-01-6111

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Disclaimer

This document is an executive briefing of a contractor's study done with the supervision and review of the Office of Pesticides and Toxic Substances of the U.S. Environmental Protection Agency. The purpose of the main study was to evaluate the economic implications of alternative policy approaches for controlling emissions of chlorofluorocarbons (CFCs) in the United States.

The briefing was submitted in fulfillment of Contracts No. 68-01-3882 and 68-01-6111 by the contractor, The Rand Corporation, and by its subcontractor, International Research and Technology, Inc. Work was completed in July 1980.

The briefing is not an official EPA publication. The document can not be cited, referenced, or represented in any court proceedings as a statement of EPA's view regarding the chlorofluorocarbon industries, or of the impact of the regulations implementing the Toxic Substances Control Act.

PREFACE

This report documents a briefing presented to the Environmental Protection Agency on November 29-30, 1979. The purpose of the briefing was to summarize the results of a three-year Rand study of the economic implications of alternative policy approaches for controlling emissions of chlorofluorocarbons (CFCs) in the United States. The briefing was presented to various staff members and officials at EPA, including the Assistant Administrator for Planning and Management, William Drayton, and to the Assistant Administrator for Pesticides and Toxic Substances, Steven Jellinek. By invitation from EPA, representatives from the Council on Wage and Price Stability and the Council of Economic Advisers also attended sessions at which the briefing was delivered. Later (and with the prior approval of EPA), versions of the briefing were also presented to industry trade associations with a particular interest in the issue of chlorofluorocarbon regulation. Because of the length and complexity of the research report whose results were summarized in the briefing, this documentation of the briefing is being released as a summary for the larger report.

The research described herein was performed under Contracts 68-01-3882 and 68-01-6111 from EPA. The analysis of the refrigeration applications of chlorofluorocarbons was largely performed by International Research and Technology, Inc., under subcontract to Rand. The final report on the project is R-2524-EPA, A. R. Palmer et al., *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications*, June 1980. Two other supplementary documents concerning the study will be published in conjunction with the final report. One, by William Mooz and Timothy Quinn, is a more detailed examination of flexible foam products (N-1472-EPA). The other, by Kathleen Wolf, is a description of the industries that produce CFCs and their precursor chemicals (N-1483-EPA).

ACKNOWLEDGMENTS

Many companies, trade associations, and individuals went to extraordinary lengths to assist us in obtaining essential information for the research described in this report. Naming these individuals or companies would result in a list of perhaps 400 entries, and the list would omit the names of many people who contributed indirectly through their firm's representatives or who responded anonymously to our questionnaires. Rather than perform the injustice of selecting only a few names for explicit mention, we prefer to express implicit, but genuine, appreciation to the many industry contributors to this study.

The authors also owe a substantial debt for the special efforts of several persons at Rand. First, we acknowledge the pervasive contribution of the project's original director, George Eads, whose insights and talents laid a firm foundation for the research. The two reviewers of this report, James Dertouzos and Bridger Mitchell, showed exceptional attention to substance and detail in their comments. and deserve no blame for any remaining oversights in this final version. Martha Cooper prepared this manuscript with efficiency and skill, while our editors, Patricia Bedrosian and Mary Vaiana, made a substantial contribution to the quality of the presentation, in matters of both format and style.

Our acknowledgments would be incomplete without a mention of our original project monitor at EPA, Douglas Hale. His guidance and administrative skill were essential in allowing the research to adjust to the many, not inconsiderable "surprises" encountered along the way. James Hughes at EPA also provided valuable assistance to the project.

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I. INTRODUCTION

Several scientific studies since 1974 have indicated that chlorofluorocarbons (CFCs) can deplete stratospheric ozone that protects the earth from ultraviolet radiation harmful to human, plant, and animal life.[1] By the end of 1978, the United States had banned virtually all uses of CFCs as propellants in aerosol products, such as hairspray and other personal hygiene products. However, those bans eliminated only about half of U.S. emissions. The chemicals continue to be used in a large number of nonaerosol applications in the United States. These include: manufacture of flexible and rigid foams for cushioning, insulation, and packaging; industrial cleaning and drying of electronic components; home and food store refrigeration, and air conditioning in autos; liquid fast freezing of foods; and sterilization of medical supplies.

The research summarized in this report examines a variety of policy options for limiting CFC emissions in the United States. Because aerosol applications are already regulated, the analysis deals only with nonaerosol applications of CFCs. Our research identifies the economic costs of regulations to achieve various degrees of emissions control. The existence and potential magnitude of social, environmental, and economic benefits from reducing emissions were not examined in this study, but are being studied by other researchers.

This document reviews all the major components of the study. Section II describes the basic features of the CFC emissions process and projects future emissions in the absence of policy action. Section III identifies policy strategies for reducing emissions; these include some candidates for mandatory control policy and, alternatively, policies that would make use of economic incentives; Sec. IV explains basic concepts necessary for comparing the different policy mechanisms. The demand for CFCs, which must be estimated in order to analyze economic incentives policies, is discussed in Sec. V. Section VI compares the two types of policy along a number of dimensions, including costs to the economy as a whole and effects on the CFC-using industries.

Neither policy approach is clearly superior to the other along all the dimensions considered in this study. Consequently, the study does not recommend a particular policy strategy. Instead, the study (and this document) concludes in Sec. VII with a survey of major insights concerning the nature of the policy issues that now confront the federal government.

The following methodological observations are relevant. First, all quantitative projections extend through the year 1990; predicting even that far in the future is risky, and to go much beyond that date would be excessively so, particularly because the private firms that contributed data for this study do not project their own activities beyond that year. Second, the baseline projections of emissions are a "most likely" case, based on what industries told us about their own plans for the future. In contrast, the predictions of the outcomes of policy are very cautious.

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[1]See The National Research Council, *Stratospheric Ozone Depletion by Halocarbons: Chemistry and Transport*, 1979, and citations noted there.

When we are confronted with uncertainty, prudence dictates we should tend to err on the "safe" side. Hence, the cost estimates may be overstated and the estimates of emissions reductions may be understated. However, the caution is even-handed; it is specifically designed not to favor one policy alternative over another.[2]

Throughout the report, policy effects on emissions are measured in terms of reductions relative to the baseline case *in which annual emissions are projected to grow.* All but one of the policy designs analyzed herein would permit some growth in CFC use over the next decade, though less than in the absence of policy action.

Finally, all of the cost data reported here are measured in 1976 dollars.

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[2]The bias toward caution in the estimates tends to favor the case against regulatory action of any kind. However, this study was not designed to evaluate the desirability of regulation, which would have required an investigation of the benefits as well as the costs of ozone protection. Moreover, as explained later in this summary and in the larger report it summarizes, the study does examine the implications of alternative assumptions that might place an upper bound on emissions reductions and a lower bound on regulatory costs.

II. THE EMISSIONS PROCESS

To examine policies for reducing emissions, it is necessary to know how and where emissions occur, and how and why emissions in different product areas are changing over time. For analytical purposes, the study divides the life of final products made with CFCs into three stages represented in Fig. 1: manufacture, normal use, and disposal.

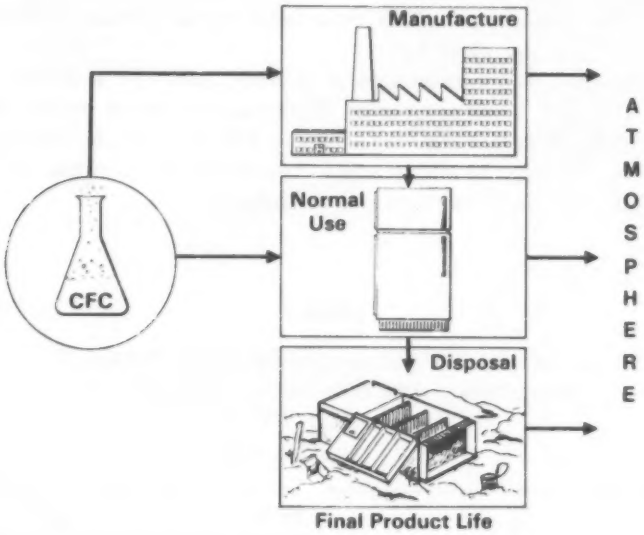

Fig. 1—The CFC emissions process

CFC is used during the manufacturing stage in all product areas. Some products such as flexible foams emit essentially all of the CFC at the time of manufacture. In this case, the CFC emissions in any year are equal to the CFC used during the final product manufacturing process in that year.

In other products, such as the refrigeration and insulation applications, the CFC performs a vital function during the normal use of the product. Although there may be some CFC emissions during the manufacturing stage, most of the CFC remains confined in the product during normal use. We call this phenomenon "banking," and the CFC retained in the product is referred to as the bank. Emissions from these products may occur during normal use, and some CFC may be replaced through servicing; but much of the CFC will not be emitted until disposal of the product, perhaps 50 years after it is manufactured. For a product of this type, the emissions in a particular year are equal to the manufacturing and servicing emissions that occur during that year plus the emissions from the CFC bank formed by prior years' production of the product.

Virtually all the CFCs sold into nonaerosol applications are ultimately emitted to the atmosphere. Hence, an estimate of the eventual sum of manufacturing, normal use, and disposal emissions can be obtained directly from estimates of CFC use over time. The magnitude of emissions during the manufacturing stage is relatively well-known, since manufacturers generally pay close attention to material losses. The division of emissions between normal use and disposal is debated, but while this uncertainty affects estimates of the timing of emissions, it has relatively little effect on estimates of cumulative emissions over long periods of time. However, the particular emissions characteristics of the final product do determine the point in time at which policies become effective in reducing emissions. For example, policies that affect the amount of CFC retained in a product may not have an impact on emissions until many years later.

Table 1 reports baseline estimates of 1976 and 1990 CFC purchases (sales) and emissions in several product categories. The values are based on industry-supplied data and on models of the emissions process in individual product areas. More than 200 firms were contacted to obtain this information, and our interim reports containing the information were reviewed by industry.

Table 1

ESTIMATED CFC SALES AND EMISSIONS FROM U.S. NONAEROSOL APPLICATIONS IN 1976 AND 1990 (EXCLUDING CFC-22)[a]
(Millions of Pounds)

Analyzed Applications	1976		1990	
	Sales	Emissions	Sales	Emissions
Mobile air conditioning	90	76	125	122
Solvents	69	69	147	147
Flexible foams	34	34	72	72
Rigid foams	60	33	226	113
Other refrigeration	30	27	39	33
Miscellaneous	23	23	70	64
Total	306	262	679	551
Other Applications	51	51[b]	47	47[b]

[a]Calculations were performed from data presented in Adele R. Palmer et al., *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications*, The Rand Corporation, R-2524-EPA, June 1980. Annual sales do not necessarily equal annual emissions because of CFC banking.

[b]Estimated emissions figures assume all CFCs are promptly emitted because of lack of information on banking in these applications.

The product areas represent the major applications of several CFCs. The most commonly used are CFC-11, 12, and 113, all of which are fully halogenated.[3] We do not incude here, or elsewhere in this report, uses of CFC-22. The latter CFC is not fully halogenated, and for that reason, it is thought to pose less of a hazard to the ozone layer.[4]

CFCs perform various functions in the different product areas. CFC is the refrigerant in automotive air conditioning units. It is a solvent used in metal cleaning and for the defluxing of printed circuit boards. It is a blowing agent that forms the cells or "bubbles" in flexible foams used for cushioning in furniture, bedding, and carpet underlay applications. The rigid foams category includes two types of products: insulation and packaging. The CFC acts as an insulating medium as well as a blowing agent for rigid insulating foams used in the construction of homes and offices, and as a blowing agent in rigid packaging foams. CFC is the refrigerant in three types of refrigeration devices: in chillers used to cool large industrial and commerical buildings, in home refrigerators and freezers, and in display and storage cases used in retail food stores. The "other refrigeration" category shown in Table 1 combines uses in all three of these applications.

CFC is used in a variety of other ways represented here by the miscellaneous category. The largest applications in this category are in the liquid fast freezing of food and in the sterilization of hospital supplies.

As Table 1 indicates, annual CFC purchases do not equal CFC emissions in certain of the product areas. This is a result of the banking phenomenon.

Both total purchases and emissions are growing rapidly and will approximately double by 1990. The largest rate of increase in emissions for the period is in rigid foams, followed by flexible foams and solvents. Although mobile air conditioning is a large current source of emissions, it is not growing as rapidly. Note that the "other refrigeration" category, composed of three refrigeration applications, is a small contributor to emissions in 1976; in 1990 it is the smallest emitting category. This last observation is important because refrigeration has often been mentioned as an important product area that might have to be sacrificed to achieve substantial emissions reductions—a speculation that is not supported by the data in Table 1.

Because of the growth in certain CFC-using products, the CFC bank is growing rapidly. Table 2 lists the major product areas that retain CFC and thereby contribute to the bank. These three categories—insulating foams, vehicle air conditioning, and other refrigeration—account for more than 90 percent of CFC banking.

The bank is an important source of future emissions. Even if all sales of CFCs were immediately banned in the United States, the emissions potential from the existing (1980) bank of CFCs is such that total cumulative emissions over the period 1980 through 1990 would be reduced by only 85 percent. In the absence of regulatory action to limit banking, the total bank will approximately triple by 1990, dominated by increased banking of CFC in insulating foam.

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[3]A fully halogenated CFC molecule contains only chlorine, fluorine, and carbon, and has no double or triple bonds between carbon atoms.

[4]The omission of CFC-22 accounts for the omission of home air conditioners from the products we examined.

Table 2

ESTIMATED SIZE OF THE U.S. BANK OF CFC IN 1976 AND 1990 (EXCLUDING CFC-22)[a]

Product Area	CFC Bank (millions of lb) 1976	1990
Rigid foams	250	1291
Mobile air conditioning	222	384
Other refrigeration	201	274
Total	673	1949

[a]Calculations were based on analysis reported in Palmer et al. (1980).

III. POLICY STRATEGIES

A number of commercially available technical options exist for controlling CFC emissions from the manufacture, service, and disposal of nonaerosol products. The available technical options fall into one of three general categories: recovery and recycle of CFCs before their escape into the atmosphere, substitution of alternative chemicals for CFCs, and improvements in manufacturing equipment to help reduce the rate at which CFCs escape into the atmosphere. One or more of these types of options is currently available in several of the nonaerosol product areas, though there are no commercially available options in some applications. To achieve near-term reductions in emissions beyond those available through increased implementation of existing technical options, it would be necessary to restrict the availability of some or all products made from CFCs.

Table 3 lists the four general policy strategies available to EPA for achieving emissions control. The first of the strategies, CFC bans, directly prohibits the use of CFCs in some or all applications, and would represent an extension of the current aerosol regulation to nonaerosol applications. In this study, policies that would eliminate nonaerosol products from the U.S. market were not a focus of quantitative analysis; however, a few qualitative comments about this policy approach are noted in Sec. VII.

Table 3

POLICY STRATEGIES

o CFC bans.
o Voluntary action programs.
o Mandatory controls.
o Economic incentives.

Voluntary action programs can take two forms. First, they might consist of "jawboning" or other encouragement to firms to implement known technical options. The detailed analysis in our study investigates the costs of alternative technical options and can thus provide some insight into the cases in which encouragement is least likely to encounter serious resistance, but it is impossible to predict with any confidence how effective specific encouragement might be; we make no attempt to render such predictions. Second, EPA might provide information or research and development services to industry. Such a program might be more effective than simple encouragement because it shifts some of the costs of regulation from firms to the government. Beyond this qualitative inference, which is reiterated in Sec. VII, this study does not investigate the costs or prospective benefits of voluntary action programs.

The last two policy strategies listed in Table 3 are the focus of the quantitative analysis of this study. By mandatory controls, we mean regulatory requirements that specify the technical options firms must use to control emissions.[5] In contrast, economic incentives function by making CFCs costly enough that firms would find it cost-saving to implement technical options that reduce their use and emissions of virgin (newly produced, as opposed to reclaimed) CFCs.

We began our policy analysis by examining all currently available technical options for reducing emissions in each of the product areas. For each option, we determined the cost to industry of a mandatory requirement to use the option as well as the CFC price required to induce industry to use the option under an economic incentives policy.[6]

Next, to compare the costs of alternative policies, it was necessary to identify policy designs that would be equally effective in reducing emissions. For this purpose, we identified a set of technical options as candidates for mandatory controls, thereby establishing a benchmark level of emissions reduction.

The technical options included in the benchmark had to meet three criteria: First, they had to be enforceable at reasonable levels of monitoring and enforcement activity. If a technical option were very costly to industry, so that there were strong incentives for noncompliance, *and* if effective enforcement required virtually continuous monitoring at many different sites, we judged the option unenforceable. Two of the unenforceable options that prove to be especially important in this analysis are: substitution of methylene chloride for CFC-11 in flexible foams, and substitution of alternative solvents for CFC-113. In both of these cases, it would be very difficult to be sure the substitution occurs on a continuous basis without taking the relevant CFC off the market altogether—which would effectively ban the production of certain products that cannot be made without these CFCs. Perhaps even more important, substitution in these cases is a poor candidate for a mandatory requirement because the substitute chemicals are currently under investigation themselves as potential hazards to health or the environment. Note, however, that some firms would find it less costly to convert to an alternative chemical than comply directly with CFC mandatory controls and that conversion to alternative chemicals could be induced by an economic incentives policy; these possibilities are reflected in our analysis.

Our second criterion for the benchmark is that the options had to be effective by 1990. Nearly all the technical options that reduce the amount of CFC banking in final products would take several years to mature because of long delays for research and development and for industry retooling, and because the newly made products would not fully replace those with higher normal use emissions until the products already in use are replaced. If these slow-maturing options had been included in the benchmark as mandatory controls, all of their costs and little of their emissions effects would have been apparent in the data estimates through the

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[5]Another mandatory control approach would be simply to specify the degree to which emissions must be limited without specifying how. If it is assumed that such regulation is designed to permit continued production of final products, then the extent of emissions reduction that can be achieved in this way is dependent on existing technology and will be similar to emissions reductions under policies that specifically require implementation of current emissions-limiting technology.

[6]In all product areas, historical data proved inadequate for empirically estimating industry responses to CFC prices. Consequently, CFC demand schedules were estimated by determining the CFC price necessary to justify the capital investment and operating costs for each technical option.

year 1990, thus putting the controls at an apparent disadvantage in comparison with economic incentives policies. The slow-maturing options *are* analyzed in the study, but they are omitted from the quantitative analysis of the benchmark control candidates.[7]

Third, a technical option could not be included in the benchmark set of controls if there were insufficient data to estimate costs or effectiveness. In most cases, these options are still on the drawing boards and will not be commercially available for several years; while they might be very promising prospects, regulations requiring their use could not be implemented anytime soon and so their cumulative emissions effects by 1990 would be limited. In a few cases, technical options might be commercially available, but lack of relevant data means they could not be implemented by EPA without further technical assessment.

The mandatory controls that met the three criteria for inclusion in the benchmark are listed in Table 4. Some product areas had no technical options that met the criteria and would thus be unaffected by the benchmark control policy.

Table 4

BENCHMARK MANDATORY CONTROL OPTIONS

- Flexible foams: recovery and recycle of CFC-11 in slabstock and molded flexible foam plants.
- Solvents: equipment standards for users of CFC-113 in cleaning and drying applications.
- Rigid foams: recovery and recycle of CFC-12 in thermoformed extruded polystyrene sheet plants.
- Chillers: conversion to CFC-22 test gas at manufacture.
- Retail food refrigeration: conversion to CFC-22 test gas in manufacture.
- Retail food refrigeration: conversion to R-502 refrigerant in medium-temperature (nonfreezing) systems.

Table 5 shows the estimated effectiveness of the benchmark mandatory controls in reducing emissions below baseline levels. If implemented in 1980, the controls would cause 1980 CFC use and emissions to drop below 1979 levels. However, use and emissions would increase in succeeding years as production of final products increases.

The largest emissions reduction is obtained through the recovery and recycle of CFC during the manufacture of flexible foam. Requiring equipment standards for solvent users and the recovery and recycle of CFC in the manufacture of

[7] Analyses of the slow-maturing options are not reported here but are documented in Palmer et al. (1980).

Table 5

ESTIMATED EMISSIONS REDUCTIONS UNDER THE BENCHMARK MANDATORY CONTROLS[a]

Product Area	CFC	Annual Reductions in Emissions[b] (millions of lb) 1980	1990
Flexible foams	CFC-11	26.5	40.5
Solvents	CFC-113	10.0	32.5
Rigid foams	CFC-12	7.2	11.3
Retail food refrigeration	CFC-12	1.0	4.0
	CFC-502[c]	-0.7	-3.9
Chillers	CFC-12	0.1	0.1
Total	Non CFC-22[d]	44.1	84.6

[a]Calculations were based on analyses presented in Palmer et al. (1980).

[b]Reductions are measured relative to baseline emissions that are expected to grow over the next decade.

[c]The negative signs for CFC-502 emissions effects indicate emissions of this CFC would increase under the benchmark controls.

[d]The totals for non-CFC-22 exclude the 48.8 percent of CFC-502 that is composed of CFC-22.

extruded polystyrene sheet (a rigid packaging foam) both lead to substantial emissions reductions. The substitution of CFC-502 for CFC-12 in new medium temperature retail food store units decreases emissions of CFC-12, but also simultaneously increases emissions of CFC-502; on balance, however, there is a net improvement in ozone protection because CFC-502 is a less hazardous CFC.[8] In retail food store refrigeration and chillers, manufacturers currently use CFCs to test whether the units will hold a refrigerant charge; substitution of other test gases would lead to minimal decreases in emissions.

An alternative to mandatory controls is the use of economic incentives. They function by raising CFC prices. Confronted with sufficiently high prices, users will find it cost-saving to conserve CFCs by recovery and recycling, improving equipment, and substituting other chemicals. Since virtually all the CFC that is used is ultimately emitted, reducing use reduces emissions.[9]

We examined two alternative mechanisms for raising prices. The first raises the price directly by taxing CFCs. The second raises the price indirectly by setting

[8]CFC-502 is about half CFC-22, which is not fully halogenated.

[9]As a practical matter, the incentives policies we studied would have little effect on banking, so reductions in annual use would be nearly equal to reductions in annual emissions.

a quota on CFC sales. A quota that creates a shortage would encourage the CFC producers to raise their prices. Alternatively, the regulatory agency could issue permits (ration coupons) that the user must have in order to buy CFCs. The permits would be marketable; users could sell them to each other. The price of the permit in this case represents an increase in the cost of purchasing CFCs.

Taxes and quotas share several important features that distinguish their effects from those of mandatory controls. First, both types of economic incentive policies are self-enforcing for users. Enforcement consists of collecting the appropriate revenues from taxes or monitoring CFC production.[10] It is not necessary to monitor users because their own self-interest encourages them to conserve CFCs and control emissions. An implication is that some technical options users would resist under mandatory control policy would be implemented under the economic incentive generated by higher CFC prices.

Second, economic incentives can be fine-tuned to reflect the differences among CFCs in potential hazard to the ozone layer caused per pound of emissions. This is achieved by raising prices more for the most hazardous CFCs. Making the most hazardous CFCs the most costly encourages emissions reductions where they do the most good.

Finally, economic incentives offer a more flexible time profile of annual emissions and costs than do mandatory controls. The emissions effects under the benchmark mandatory controls depend on the assumption that the controls would be instituted immediately and fully enforced every year through 1990. If implementation or enforcement were changed, the emissions outcome would change also. In contrast, there are many different economic incentive policy designs that can achieve the same cumulative reduction in emissions. For example, the same cumulative goal can be reached by holding a tax constant throughout the period, or by setting a low tax initially and raising it gradually over time. Similarly, a given cumulative effect can be achieved through many different patterns of annual quotas.

There are operational differences between taxes and quotas that are discussed later in this report. However, the increase in CFC prices that is consistent with a given reduction in CFC use is the same whether taxes or quotas are used. This similarity allows us to treat the two types of economic incentives as equivalent in much of our analysis. At the same time, the features that distinguish incentives from mandatory controls require us to establish some common bases for comparing the two policy strategies; the bases for comparison are addressed next.

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[10]This implicitly requires controls on CFC imports.

IV. BASES OF POLICY COMPARISON

Because the mandatory control and economic incentives policies differ in major ways, we needed to develop common bases for comparing them. Table 6 shows our approach.

Table 6

BASES FOR POLICY COMPARISON

- CFC emissions weighted by chlorine content: "permit pounds."
- Effectiveness: cumulative emissions reductions below baseline, 1980 through 1990.
- Costs: discounted cumulative, 1980 through 1990:
  - -- To economy as a whole: resource costs.
  - -- To user industries: resource costs plus transfer payments.
- Other policy concerns, e.g., substitution of hazardous chemicals for CFCs

As we noted earlier, different CFCs are believed to impose different levels of hazards to the ozone layer per pound of emissions. Since mandatory controls and economic incentives can differ in the mix of CFCs whose emissions are reduced, it is necessary to develop a common basis of emissions measurement that yields comparable estimates of ozone protection. The "permit pound" is such a measure; it weights the CFCs according to chlorine content, a factor that is critical in determining the potential hazard of the various fully halogenated CFCs. For example, when a pound of CFC-502 is substituted for a pound of CFC-12 in retail food refrigeration, emissions decline by 0.75 permit pounds.

Mandatory controls and economic incentives can yield quite different time profiles of annual emissions, but in comparing the overall effectiveness of the two policy strategies, we use cumulative emissions from 1980 through 1990. This simplification was suggested to us by EPA and is based on the assumption that the ultimate damage to the ozone layer from a given amount of emissions is independent of the timing of the emissions within a decade.[11]

Mandatory controls impose costs on user industries by requiring firms to make expenditures on capital, labor, energy, and other resources used to limit emissions. Economic incentives also cause firms to buy resources. However, the levels of

[11]There may be some slight difference in the timing of the ultimate emissions effect. However, because the ultimate effect is several decades in the future, discounting the future ozone effect to take account of differences in timing would not yield noticeable changes in the differences between the measured effectiveness of different policies.

resource expenditure can differ between the two policies even when their effectiveness in reducing emissions is equal. The reason is that the technical options used to reduce emissions under the alternative policies can differ; in particular, incentives induce some users to implement options that would be difficult to enforce under a mandatory control strategy.

The resources expended to control CFC emissions cannot be used to produce other goods and services. Hence the resource costs imposed by policy represent an economic cost to the economy as a whole, and form one important basis for comparing the economic implications of alternative policy strategies.[12] Since the time profile of annual resource costs can differ between the two policies—and since industry is not indifferent to when costs are incurred—we compare the sum of annual resource costs, discounted at 11 percent per year.[13]

Costs to the economy as a whole are not the only basis for comparing the economic implications of alternative policies. The distribution of costs is also important because of its implications for the prices of consumer products and the likelihood of plant closures and worker unemployment in various industries. Resource costs are distributed among CFC-using industries differently under mandatory controls and economic incentives, even when the policies are equally effective in ozone protection. Moreover, economic incentives policy can impose another type of expense on user industries that is not imposed by mandatory controls: transfer payments.

Depending on how an incentives policy is implemented, firms might have to pay taxes, buy permits, or otherwise pay higher prices for the CFCs they continue to use. These payments do not reflect increased purchases of resources and thus do not restrict the ability of the rest of the economy to produce other goods and services; instead, the payments return to the economy elsewhere, for example, when the government uses the tax revenues to pay for various government programs. In short, the payments transfer wealth away from CFC users to the rest of the economy. Transfer payments are an added expense in the industries that pay them, and can contribute to higher consumer prices, plant closures, and worker unemployment in those industries.[14] To compare the distribution of industry expenses under mandatory controls and economic incentives, therefore, it is necessary to compare the resource costs under controls with the sum of resource costs and transfer payments under economic incentives. Like our measure of resource costs, the summary measure of industry expenses is the discounted sum of annual expenses from 1980 through 1990.

There are several other bases for policy comparison, such as effects on the use of substitute chemicals that might be hazardous to health or the environment. Those effects are also discussed below.

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[12]The larger report on which this document is based uses the term "compliance costs" to refer to resource costs.

[13]Eleven percent is used for consistency with other CFC research sponsored by EPA and is currently the estimated real rate of return to nonconstruction investment.

[14]Because the transfers return to the economy elsewhere, there should be offsetting effects on prices and employment in other industries.

V. CFC DEMAND

We determined the effects of economic incentives on CFC use by estimating annual CFC demand curves like the one shown in Fig. 2 for the year 1980. The vertical axis measures the price increase per permit pound resulting from policy action. Because the permit pound weights more hazardous CFCs more heavily, a given tax or permit price per permit pound yields larger price increases for more hazardous CFCs.[15] Use is measured in permit pounds, summed over all CFCs and applications.

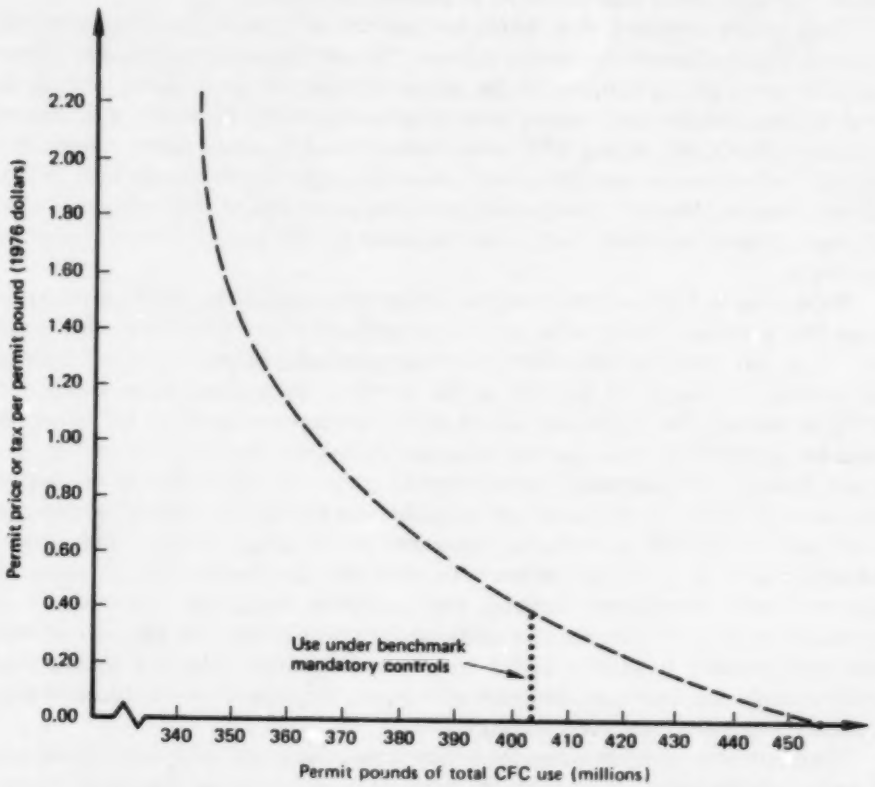


Fig. 2—1980 demand schedule for use of fully halogenated CFCs

[15]One permit pound is equivalent to one pound of CFC-113, 0.73 pounds of CFC-11, 0.97 pounds of CFC-12, or 3.87 pounds of CFC-502. Consequently, a tax or permit price of 10 cents per permit pound would raise the price of CFC-113 by 10 cents; the price of CFC-11 by 13.6 cents; the price of CFC-12 by 10.3 cents; and the price of CFC-502 by 2.6 cents. Supplier prices of the CFCs are assumed to remain constant in real terms from 1980 through 1990, except for the CFC-113 price which is projected to decline to 40 cents (in 1976 dollars) by 1990.

In the absence of policy action, the tax or permit price is zero, users pay only the CFC sales price, and 1980 use would amount to about 450 million permit pounds. As the CFC price increases, some of the technical options we studied become cost-saving to firms, and CFC use declines accordingly. The higher the CFC price, the more costly are the options that will be used.

The dotted line in the figure indicates the 1980 level of use under the benchmark mandatory controls. It is very unlikely that mandatory controls could be used to reduce CFC use much further, because all the enforceable, immediately effective, and commercially available technical options are included in the controls. However, further reductions would be possible by increasing the tax or permit price. Raising it to as much as $2 could reduce 1980 CFC use by at least 25 percent.

The analysis of the CFC demand curve is based on the assumption that demand for final products made from CFCs is very inelastic (unresponsive to higher prices). Consequently, all the reductions in CFC use shown in the demand curve are presumed to be due to implementing technical options that reduce use and emissions while holding final product output constant. A further implication of the inelasticity assumption is that cost increases in user industries would be passed through to consumers in the form of higher product prices.

For small changes in the CFC price, the inelasticity assumption is reasonably accurate; in nearly all product areas, CFCs account for only a small percentage of final production costs, so even doubling the CFC price (current price levels for various CFCs range from 34 cents to about $1.50) would increase final product prices by much less than five percent. We expect most consumers to pay the higher prices. However, as the CFC price rises further, it becomes more likely that demand for the final product will be affected; thus the reductions in CFC use shown in Fig. 2 increasingly understate the likely effect of higher CFC prices. When taxes or permit prices exceed $2 per permit pound, the likelihood of curtailed production of final products becomes substantial, and plant closures in at least some user industries become more likely.

Given the estimated CFC demand curve, large reductions in use (25 percent or more) appear difficult and costly to achieve. To some degree, the cost might be overstated because there may be some technical options that could not be analyzed because of inadequate data on their costs and effectiveness. One of our "cautious" assumptions is that these options are so costly to implement that firms would not use them unless CFC prices rise by more than $2 per permit pound. A less cautious assumption is used later in this report to generate a lower-bound estimate of the costs of stringent reductions in CFC use.

VI. OUTCOMES OF ALTERNATIVE POLICIES

COSTS TO THE ECONOMY AS A WHOLE

The benchmark mandatory controls would reduce cumulative emissions by a little over 800 million permit pounds—15 percent of the baseline estimate—and would cost the economy $185 million over the period. An equally effective economic incentive policy would require CFC prices to rise by about 50 cents per permit pound, whether through a tax or a quota. Overall, the incentives policy would cost the economy only $108 million (cumulative), about 40 percent less than the equally effective mandatory controls.

To understand why economic incentives are less costly to the economy even when they achieve the same emissions reduction as the mandatory controls, it is useful to look at outcomes by product area displayed in Table 7. Economic incentives cause much larger emissions reductions in solvent applications, where chemical substitution is a relatively low-cost way to reduce CFC use and emissions. With solvents carrying more of the burden of emissions reductions, rigid packaging foam applications do not have to pursue as much costly recovery and recycling. Basically, economic incentives generate lower compliance costs because they redistribute emissions reductions from high- to low-cost activities.

Economic incentives policies can be designed to achieve even larger emissions reductions than the benchmark. The most stringent policy design we examined

Table 7

PRODUCT AREA OUTCOMES UNDER MANDATORY CONTROLS AND EQUALLY EFFECTIVE ECONOMIC INCENTIVES[a]

	Cumulative Emissions Reductions, 1980-1990 (millions of permit pounds)		Discounted Cumulative Resource Costs (millions of 1976 $)	
Product Area	Mandatory Controls	Economic Incentives	Mandatory Controls	Economic Incentives
Flexible foam	501	381	93	29
Solvents	186	390	46	67
Rigid packaging foam	106	27	39	4
Retail food	18	18	7	7
Chillers	1	1	<1	<1
Total	812	817	185	108

[a]Calculations based on data in Palmer et al. (1980).

would double the effectiveness of the benchmark-equivalent policy, reducing cumulative emissions by about 30 percent. This policy is described as a "zero-growth" design because it would reduce cumulative emissions by the same amount as a policy that holds annual CFC use constant at 1980 levels throughout the period. However, the actual design of this policy in our analysis is such that there would be a drop in use in the first year of the policy followed by some growth from that level over the remainder of the period. This design is less costly than true zero growth because relatively inexpensive reductions in the early years of the policy can be used to offset higher use and emissions later on. Resource costs under our zero-growth design would accumulate to $600 million (discounted) over the period. We cannot estimate the costs of a policy that actually holds growth to zero because the necessary increase in 1990 CFC prices would be beyond the range of the demand-curve estimates based on our cautious assumptions.

Table 8 summarizes the findings for the mandatory controls and the two economic incentives policies just described.[16]

Table 8

Summary Comparison of Policy Effects[a]

Policy Options	Cumulative Emissions Reductions (millions of permit pounds)	Discounted Cumulative Compliance Costs (millions of 1976 $)
Benchmark mandatory controls	812	185
Economic incentives		
Benchmark-equivalent	816	108
Zero-growth	1602	268-600

[a]Based on calculations reported in Palmer et al. (1980).

All the predictions of policy effects shown in Table 7 are based on cautious assumptions that yield rather inelastic demand curves, like the one for 1990 shown by the solid curve in Fig. 3. Given such a curve, large reductions in emissions appear very costly. However, our cautious assumptions probably overstate the costs of stringent policies.

Consider, for example, our assumption that technical options would not be used in applications where data are scant or unreliable. Suppose, instead, that these applications are just as responsive to CFC prices as the applications with better data. Then the demand curves would be much more elastic, like the dashed one in Fig. 3. If the curves are more elastic, the tax or quota policy required for the zero-growth case would be less than half as costly ($268 million) than the more cautious assumption implies. If the alternative assumption is accurate, a zero-growth policy would achieve about twice the emissions reduction of the benchmark mandatory controls at less than one-and-a-half times the cost.

[16]For economic incentives, a low-growth policy design and a cost-minimizing benchmark-equivalent design are also analyzed in the larger report summarized here.

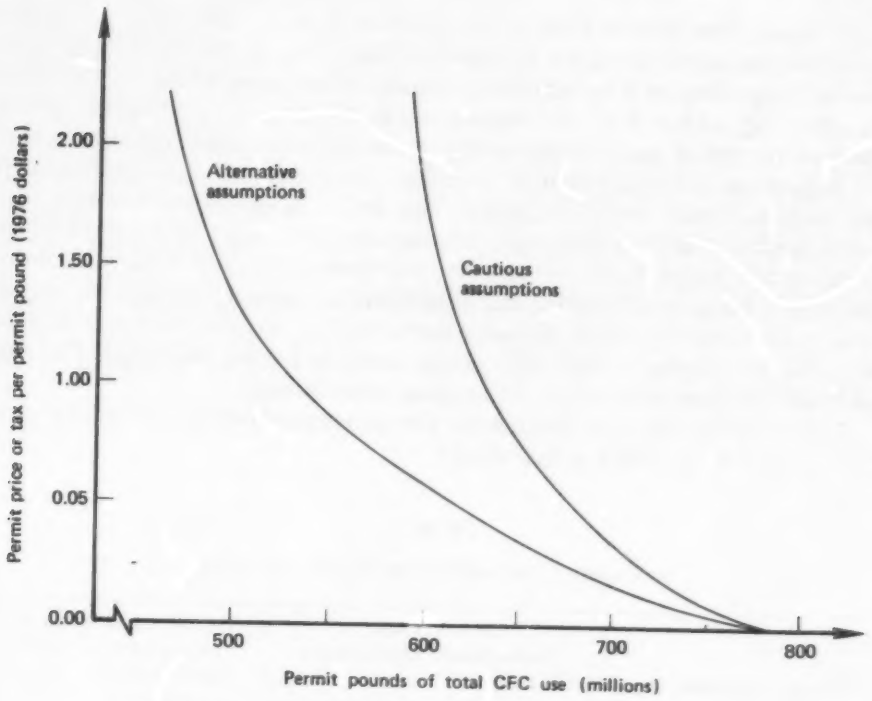


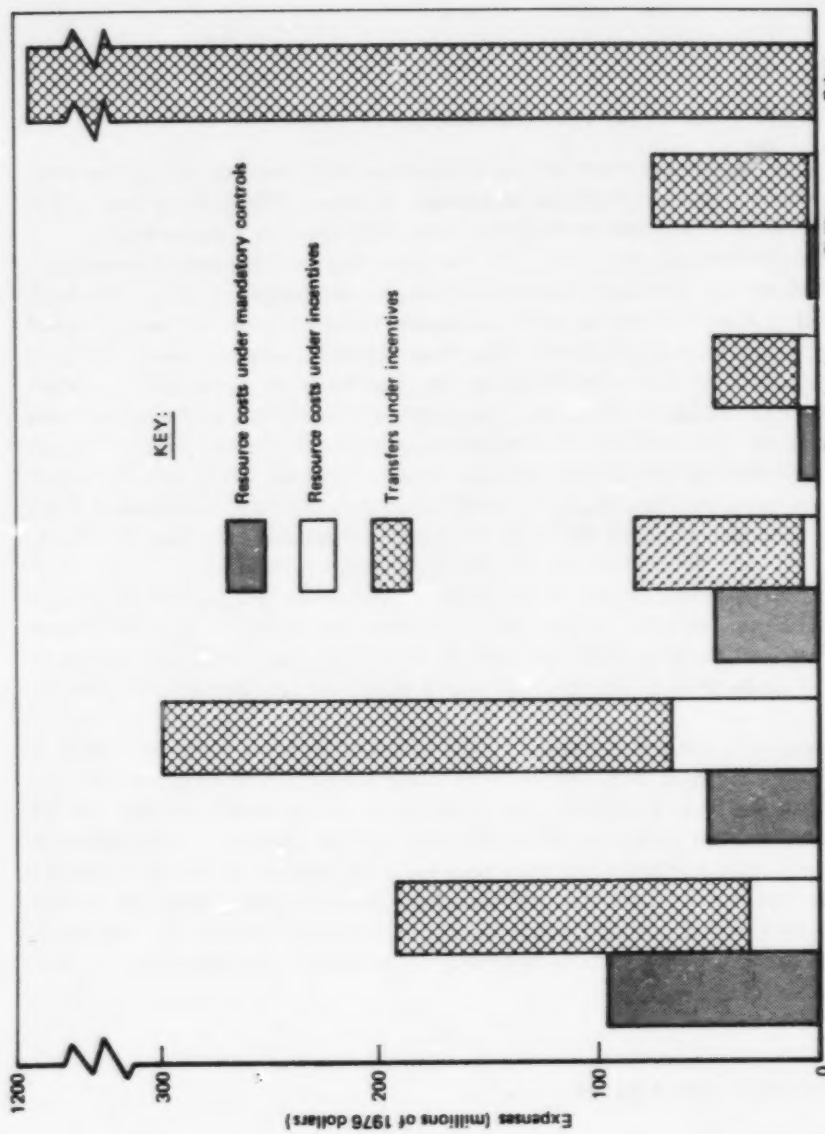
Fig. 3—Alternative estimates of 1990 demand schedules for fully halogenated CFCs

USER INDUSTRY EXPENSES

On the basis of compliance costs and emissions effects alone, economic incentives are attractive alternatives to mandatory controls. But to get a more complete picture of economic incentives, it is necessary to consider the transfer payments they can generate.

Figure 4 shows total industry expenses to achieve the benchmark emissions reduction. Compliance costs under economic incentives are shown by the unshaded bars, while compliance costs under mandatory controls are indicated by the solid bars. The cross-hatched bars are transfer payments. As Fig. 4 indicates, the cost of transfer payments can dwarf compliance costs, but expenses vary widely from one product to another. For example, in retail food, transfer payments make total expenses five times as great under economic incentives as under mandatory controls. But in rigid packaging foams, total expenses under incentives are only about twice as high as under controls. The comparison differs within product areas as well. In fact, for some small producers of rigid packaging foams, total expenses are actually less under incentives—though this situation is clearly the exception rather than the rule.

For industries that do not use technical options to reduce CFC use, transfer payments would be the only expense under an economic incentives policy. If we



[a] Benchmark - equivalent policy, constant - price design.

Fig. 4—Cumulative industry expenses under mandatory controls and uncompensated economic incentives[a]

take all the product areas where our cautious assumption is that no reductions in CFC use would be induced by an incentives policy, and we add in all product areas that have no known technical options, we get the transfer payments indicated by the right-hand bar in the figure. Combined, these product areas would pay $1.7 billion in transfers—about two-thirds of all the transfer payments generated by the policy.

MITIGATING TRANSFER PAYMENTS

Although transfer payments do not represent a real resource cost to the economy as a whole, they are clearly large enough to cause difficulties in user industries. However, it is possible to mitigate these difficulties in various ways.

One straightforward approach would be to exempt certain product areas from the policy. However, there are three disadvantages of exemptions. First, the product areas that are expected to yield emissions reductions cannot be exempted without reducing the policy's effectiveness; thus, transfer payments would continue to pose a problem for several user industries. Second, even some of the product areas that are not expected to reduce emissions in our analysis might actually have technical options that could reduce emissions; exemptions of those products would remove the incentives for use of available technical options. Third, other product areas do not have technical options simply because in the past economics did not encourage their development. Exemptions would perpetuate that state of affairs, generating no inducement for new technology to control emissions.

An alternative to exemptions is the use of compensation techniques. The design of such techniques was not a focus of this study, but we have identified some promising approaches that might be used. For example, permits could initially be allocated to users free of charge.[17] Or users might be reimbursed for transfer payments.

The design of a compensation policy is a complicated issue in its own right. A basic principle that must be preserved is that the compensation policy should not interfere with the basic incentives the larger policy is intended to create; not all forms of compensation policy would satisfy this principle. Moreover, compensation policy is likely to be politically sensitive because it requires decisions about who to compensate and at what level. Nevertheless, compensation policy deserves further study because it would permit the use of economic incentives that are less costly to the economy as a whole without imposing unnecessary expenses on user industries.

OTHER POLICY CONCERNS

There are other bases for evaluating policy aside from emissions effects, cost to the economy as a whole, and user industry expenses. Four important concerns

[17]The permits would still have a price in the aftermarket in which CFC users buy and sell permits among themselves.

are consumer prices, plant closures, potential predatory behavior, and risk trade-offs.

Because in most product areas CFCs represent a very small fraction of total production costs, regulation causes only modest increases in final product prices. Under mandatory controls, the price increases would generally be much less than 5 percent. Under economic incentives, the price effects would be somewhat greater because of transfer payments, but in principle these would be offset by price reductions elsewhere in the economy.

We do not expect large numbers of plant closures, especially under mandatory controls or compensated economic incentives, for much the same reason that only small price increases are expected. Most closures will occur in businesses whose survival is already borderline. However, one product area that might be especially susceptible to closures is rigid packaging foams, where paper and cardboard are major competitors. Notably, for this product area, either mandatory controls or economic incentives policies would pose some danger of plant closures.

Predatory behavior refers to any attempt by a small number of firms to buy up all the permits to drive their competitors out of business. The possibility appears exceedingly remote, and easy to deal with if it arises. In 1980 alone, there would be 400 million permits under the benchmark-equivalent policy. It would cost a firm at least a quarter of a billion dollars to control this market for that single year. To prevent this, Congress could provide authority for the same types of antitrust regulations that apply to securities and commodities markets.

Risk trade-offs refer to the fact that CFC regulation encourages substitution of alternative chemicals. Among the substitutes in various product areas are methylene chloride, methyl chloroform, perchloroethylene, and pentane. Each of these is suspect as some type of health or environmental hazard. Hence, CFC policy involves trade-offs among risks to health and the environment. These trade-offs are more important under economic incentives because that policy would induce more chemical substitution, especially in solvents and flexible foams applications. However, some substitution occurs even under the mandatory controls because it is cheaper for some firms to substitute another chemical than to comply directly with CFC regulation.

VII. SUMMARY OF INSIGHTS INTO THE POLICY CHOICES

This section reviews some of the important insights this research offers into the major policy choices with regard to CFC nonaerosol regulation. The choices include setting a goal for emissions reduction and selecting a policy strategy for achieving that goal. If mandatory controls are selected, further choices must be made about whether to grant exemptions to individual firms or product areas, and what level of enforcement activity to pursue. If incentives are chosen, decisions must be made about whether to use taxes or quotas, and whether to engage in compensation. Although all these matters are touched upon in the next few pages, much of the discussion focuses on choices involving incentives policies because these are far less familiar policy tools than mandatory controls.

SETTING GOALS

To a large degree, setting a goal for emissions reduction involves making a trade-off between the costs of regulation and the benefits from protecting the ozone layer. This research does not address the latter issue, but it does specify how costs vary with the level of emissions control to be achieved. Figure 5 illustrates the relationship between costs to the economy as a whole (compliance costs) and degree of emissions control. The latter variable is measured as a percentage reduction in cumulative U.S. emissions over the coming decade, and (alternatively) as a percentage reduction in cumulative world emissions achieved by U.S. policy action.

Mandatory controls occupy the lower left portion of the figure. Compliance costs are moderate, and emissions effects are modest; the benchmark controls would reduce cumulative U.S. emissions by 15 percent, world emissions by 3 percent. The effectiveness and costs of mandatory controls can be varied by changing the set of controls, changing their implementation dates, granting exemptions, or choosing among various levels of enforcement activity. But, however they are implemented, mandatory controls that require firms to use specific technologies to reduce emissions will have quite limited effects on cumulative emissions over the next decade. The effects of all the technologies that are commercially available at present and appear enforceable as mandatory controls are already reflected in the benchmark estimates. Technologies that are on the drawing boards at present might help if they measure up to expectations, but time is required for them to become commercially available and to pass through the regulatory steps required to implement them as mandatory controls; even if they are very effective in reducing annual emissions by the end of this decade, their effects on cumulative emissions between now and 1990 are limited by the magnitude of annual emissions for the years before implementation. In short, it appears most unlikely that mandatory controls could reduce cumulative U.S. emissions by as much as 40 percent.

High levels of emissions reduction can be achieved by banning the use of CFCs. While we have not researched the use of such policies, we can be sure that they

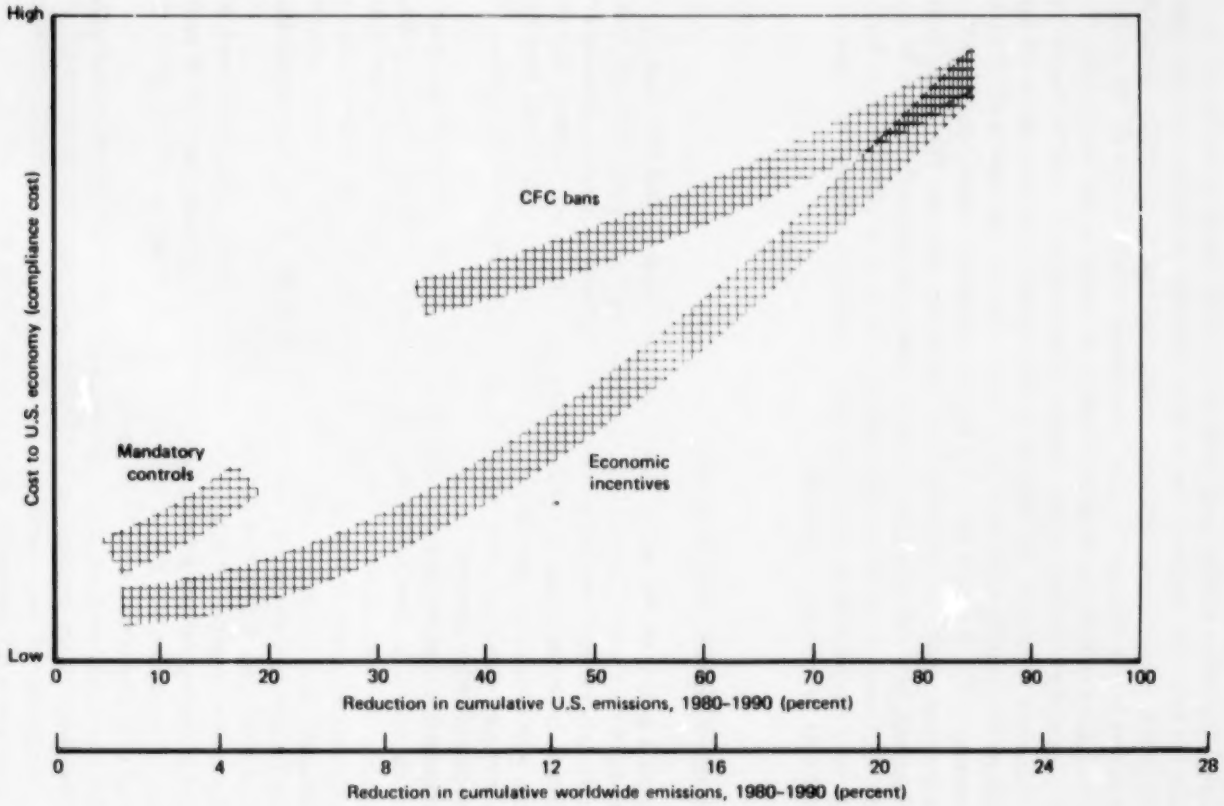


Fig. 5—Cost and effectiveness of alternative U.S. policies

would be far more costly than the mandatory controls. Note that the maximum emissions reduction that could be achieved even by a total and immediate ban on CFC use would be 85 percent, because there would continue to be emissions from the CFC bank that already exists.

Economic incentives can be used to achieve a wide range of emissions reduction. While we have not analyzed the costs of reducing emissions by more than about 30 percent, we do know that costs would rise rapidly if further emissions reductions were to be achieved. We also have reason to believe that for the middle range of emissions reductions, economic incentives would be less costly than CFC bans; the costs of the two policy approaches become similar only near the maximum level of emissions reduction. The reason is that incentives policies cause all less costly options for limiting emissions to be used before any product is eliminated.

In summary, Fig. 5 shows that, for modest emissions reductions, the policy choice is between economic incentives and mandatory controls. For larger emissions reductions, however, the policy choice is between economic incentives and CFC bans. Furthermore, even the most stringent of the U.S. policy options would have only very modest effects on total worldwide emissions unless other countries also participate in reducing emissions.

CONTROLS VERSUS INCENTIVES

Suppose a goal is set for which both mandatory controls and economic incentives are effective. Figure 6 lists some of the factors that might influence the choice between the policies. Economic efficiency, which is greater when resource costs are low, is greater under economic incentives. Moreover, this is true not only over the short run, when technical options are fixed, but it is also true in the long run because economic incentives also induce innovations to help reduce emissions in the most cost-effective manner.

By implementation, we mean the full set of activities involved in promulgating a regulation; such activities include dealing with legal challenges, collecting data, holding public hearings, and so on. Implementation is simpler to some extent under mandatory controls because this type of policy mechanism is far more familiar to EPA. Taxes are not altogether unfamiliar policies, but they are not a common technique for environmental regulation, and their implementation is complicated by the probable need to obtain congressional authority.

While implementation of mandatory controls is relatively straightforward, enforcement of the regulations is both costly and difficult because there are so many user sites to be monitored. Economic incentives are easier to enforce given the handful of CFC production sites to be monitored.

Under mandatory controls, attempts to ease the industries' transition to regulation implies delaying the regulations and thereby reducing their emissions effects. Under economic incentives, it is possible to achieve the same cumulative emissions effects while gradually increasing the incentives during the period.

Any type of regulation imposes more costs on some firms and consumers than on others. As Sec. VI showed, the total losses to CFC-using industries under manda-

Features	Controls	Incentives
Economic efficiency		Greater in short and long run
Implementation	More familiar to EPA	
Enforcement		Fewer sites to monitor
Transition		Greater flexibility
Distributive effects	Lesser effects than uncompensated incentives	Lesser effects than controls when compensated
Risk tradeoffs	Less chemical substitution	

Fig. 6—Comparison of features relevant to the choice between mandatory controls and equally effective economic incentives

tory controls are smaller than under economic incentives, unless, of course, the incentives policy is compensated.

Finally, possibly undesirable health and environmental side-effects due to chemical substitution are somewhat less under mandatory controls because they do not cause as much chemical substitution as do economic incentives.

TAXES VERSUS QUOTAS

If the policy decision is to use economic incentives, there is a choice between taxes and quotas. One major difference is in the nature of any discrepancies between actual and predicted outcomes. Given a demand curve like those estimated here, the two techniques yield the same outcomes. But if the estimated curve differs from the actual one—and we suspect that the actual curve may lie below the estimated one, as indicated in Fig. 7—a quota would increase CFC prices by less than we predict. The policy would still achieve the desired emissions reduction, but the resource cost per pound of reduction would be less. In contrast a tax would lead to emissions reductions greater than predicted.

Equally effective uncompensated tax and quota policies generate equally large transfers of wealth away from user industries. However, uncompensated tax and quota policies can differ with respect to who receives the transfers. While the tax policies cause the payments to enter the general treasury for eventual redistribu-

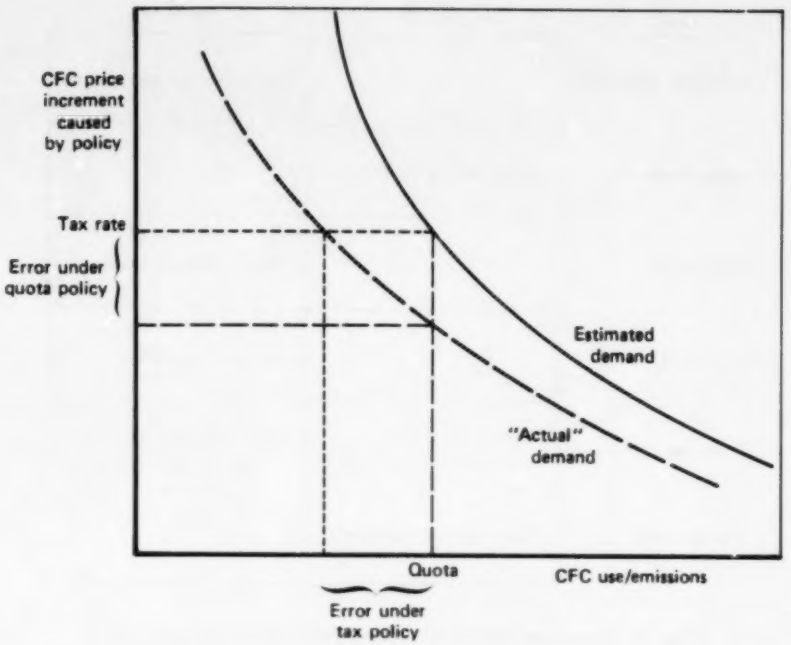


Fig. 7—Potential discrepancies between actual and estimated outcomes under taxes or quotas

tion throughout the economy, the destination of transfers caused by a quota policy depends on how the policy is implemented. If EPA sells permits under the quota, the transfers will be paid into the general treasury. However, if permits are not issued, or if they are directly allocated to the CFC producers, the producers will be the recipients of the transfers paid by CFC users.

ADVANTAGES AND DISADVANTAGES OF COMPENSATION

Because an economic incentives policy can generate large transfer payments, the regulatory agency might want to engage in compensation. Designing a compensation scheme that does not distort the policy's incentives is not a simple matter operationally. Moreover, because such a scheme involves redistributing wealth among firms and industries, it is politically sensitive. But these disadvantages must be weighed against the fact that compensation can reduce consumer price and plant closure effects—which could be considerable under a stringent goal for emissions reduction. Moreover, even mandatory controls impose more costs on some firms and industries than on others, so compensation might be considered even under mandatory controls.

VIII. CLOSING COMMENT

The CFC regulatory problem is an exceptionally complex one, spanning dozens of CFC applications in thousands of firms throughout the U.S. economy. If CFC depletion of the ozone layer warrants domestic regulation, several policy strategies —voluntary action, CFC bans, mandatory controls, and economic incentives—are available.

Each policy has advantages and disadvantages. Voluntary action, while less costly to industry, promises to be relatively ineffective in reducing emissions over the next decade. CFC bans could effectively reduce near-term emissions, but would also impose excessive regulatory costs. Mandatory controls favorably compare with economic incentives along the dimensions of ease of implementation, costs borne by the CFC-using industries, and the risk trade-offs inherent in CFC regulation. In contrast, economic incentives impose lower costs on the economy as a whole and offer far greater flexibility in both the timing and extent of emissions reductions. An incentives policy might seriously disrupt the CFC-using industries, depending on the magnitude of transfer payments; compensated economic incentives could mitigate transfer payments, but may be quite difficult to implement.

Clearly, no policy ranks first along all of the dimensions of policy comparison. Consequently, this study cannot—and does not—recommend a particular choice among the policy strategies. Ultimately, the choice will depend upon which dimensions of policy are deemed most important. That evaluation is left to the policymakers.